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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 904

WARHEAD CHARACTERISTICS

Partial Report

FRAGMENT VELOCITY LAW FOR
CYLINDER, CONES AND COMPOSITE SHAPES

Partial
Report

No. 11

Task
Assignment NPG-Re3d-442-1-52

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NPG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

PART A

SYNOPSIS

1. Cylindrical warheads with axial cavities were detonated for fragment velocity measurements. Three each of three types of Composition C-3 loaded warheads 11"75 in diameter contained hollow axial cylinders which displaced 14.1%, 31.8% and 55.6% of the explosive. Three fully loaded cylinders were also detonated for comparison.

2. Under the conditions of this test, the removal of an axial core of explosive results in the reduction of fragment velocities as follows:

<u>Percentage of Explosive Removed</u>	<u>Charge-Mass Ratio</u>	<u>Mean Velocity</u>
0	0.9218	6070 ft./sec.
14.1	0.7913	5560
31.8	0.6281	4840
55.6	0.3997	3700

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Cylinder, Cones and Composite Shapes

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

PART B

INTRODUCTION

1. REFERENCES:

- a. Conference of BUORD and NAVPROV representatives at NAVPROV on 11 April 1951.
- b. BUORD Conf ltr NP9(Re3d-AM:bc) to NAVPROV of 20 Mar 1950.
- c. BUORD Conf ltr NF9(Re3d-AM:bc) to NAVPROV of 22 Dec 1950.
- d. Ballistics Research Laboratory Restricted Report No. 405, The Initial Velocities of Fragments From Bombs, Shell, and Grenades, by R. W. Gurney, 14 Sep 1943.
- e. Ballistic Research Laboratory Restricted Report No. 648, A Note on the Initial Velocities of Fragments from Warheads, by T. E. Steine, 2 Sep 1947.
- f. NPG Report No. 637 of 7 Sep 1950.
- g. NPG Report No. 339 of 27 July 1949.
- h. NPG Report No. 581 of 23 June 1950.

2. BACKGROUND AND OBJECT OF TEST:

The Naval Proving Ground was requested in reference (a), under authority of references (b) and (c), to determine the effect of progressively larger axial voids upon the fragment velocities obtained from a cylindrical warhead.

A previous Naval Proving Ground report, reference (f), dealt with the effect on fragment velocities of a central conduit, empty or solid, which displaced approximately 7% of the explosive by weight.

The object of the present test was to make experimental measurements on annularly loaded warheads, over a considerable range of values of charge-mass ratio so that the fragment velocities to be obtained from other warheads having this type of loading could be predicted.

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Fragment Velocity Law for
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PART C

DETAILS OF TEST

3. DESCRIPTION OF ITEM UNDER TEST:

Warheads were especially designed and fabricated for this test. The working drawing is enclosed as Appendix (A), Figure 3.

The outer wall of each warhead was of seamless steel tubing, 11⁷/₁₆ O.D., and 0⁷/₁₆ wall. The inner wall, forming the central void, was fabricated of 0¹/₃₂ sheet aluminum. The over-all length was 30⁷/₈, and the length of the annular section was 29³/₄. The annular explosive column thus has a length of 2-1/2 calibers. This was considered the minimum safe length to avoid deleterious results from end effect (references (g) and (h)).

The space between the two walls was loaded with Composition C-3 explosive. A layer of approximately one inch of the explosive extended entirely across the top of the warhead, to permit even initiation of the explosive annulus. After the warhead was placed in position for detonation, the cover plate was removed, and a tetryl pellet and an electric blasting cap were placed in the center of the one inch explosive layer, for initiation of the detonation.

Three each of four loadings were fired. The four loadings were:

Explosive Weight (lb.)	Case Weight (lb.)	Thickness of Explosive (in.)	% Explosive Removed (%)	C/N
136.29	147.85	5.315	0.0	0.9218
112.00	147.85	3.315	14.1	0.7913
92.87	147.85	2.315	31.8	0.6281
59.10	147.85	1.315	55.6	0.3997

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NPG REPORT NO. 904

**Fragment Velocity Law for
CYLINDERS, CONES and COMPOSITE SHAPES**

The chemical analysis of the steel tubing indicated the following compositions:

Chemical Analysis

C	P	S
.38	.019	.027

Spectrochemical Analysis

Si	Mn	Cr	Ni	Mo	Cu
.25	1.67	.09	.06	.49	.05

Rockwell and Brinell hardness results were:

BHN 265

Rockwell "C" 24-25.

4. PROCEDURE AND RESULTS:

Each warhead was placed vertically on a stand 13 feet high. Six plates, each 12 feet high and 6 feet wide, were located on the circumference of a circle of sixty (60) feet radius about the center of the warhead. The fragment velocities were determined by photographing, with two high-speed cameras, the detonation of the warhead, and the subsequent impacts of the fragments on the steel flash plates. An 1800 r.p.m. synchronous motor clock, and a 1 kilocycle generator and glow lamp were used to establish the time base for each camera. Detailed results are listed in Appendix (C), Figure 6 and Table I. Figure 7, Appendix (C), shows the ratio of experimental to Gurney velocities ($\sqrt{2E} = 7645$) versus percent explosive removed.

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

The mean velocities obtained were:

Rd. No.	Camera No.	Fully loaded	3"315 expl. 4" center	2"315 expl. 6" center	1"315 expl. 8" center
1	1	5930	5400		3720
	2	5890	5300		3670
2	1	6220	5750	4780	3820
	2	6180	5800	5000	3690
3	1	6060	5510	4720	3610
	2	6060	5620	4840	3690
Mean		6070	5560	4840	3700

5. DISCUSSIONS

The fully loaded warhead should produce fragments with velocities in agreement with Gurney's law (reference (d)). For a cylindrical warhead of large diameter, a very thin annular explosive layer should produce fragment velocities in agreement with Sterne's treatment of a flat plate (reference (e)). The upper limit of velocities is then set by

$$(1) \quad V = \sqrt{2E} \frac{C/M}{1 + C/2M}$$

and the lower limit by

$$(2) \quad V = \sqrt{2E} \frac{3C/5M}{1 + (C/5M)^2 (4M/3C)}$$

These limits are shown for the warheads under discussion in Appendix (C), Figure 5. It should be noted that in equation (2) (reference (e)) E represents the full value of energy per unit mass of the explosive, while in equation (1), E is believed to represent approximately 80% of the full value. In the present discussion, where equation (2) is applied to an annular warhead, the value of E is taken as equal to that used in equation (1). In Figure 5, the upper curve gives theoretical velocities computed for a cylinder, and the lower curve gives velocities for a flat plate. It should be noted that the velocities are plotted versus thickness of explosive, so that the cylinder and flat plate curves will cross where the values of C/M are 1 and 2 respectively.

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Cylinder, Cones and Composite Shapes

Because of the high explosive weight of these warheads, they were fired in a sixty foot arena. The assumption was made that the mass distributions for all the warheads were alike, and that the air retardation of the fragments could be corrected for by changing the value of $2E$ to bring the experimental velocity and the Gurney velocity into agreement for the fully loaded warheads. This was done by setting $2E = 7645$.

PART D

CONCLUSIONS

6. Under the conditions of this test, the removal of an axial core of explosive results in the reduction of fragment velocities as follows:

<u>Percentage of Explosive Removed</u>	<u>Charge-Mass Ratio</u>	<u>Mean Vel.</u>
0	0.9218	6070 ft/sec
14.1	0.7913	5560
31.8	0.6281	4840
55.6	0.3997	3700

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**Fragment Velocity Law for
Cylinder, Cones and Composite Shapes**

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Ordnance Officer
By direction

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NPG REPORT NO. 904

**U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA**

Tenth Partial Report

on

Warhead Characteristics

First Partial Report

on

Fragment Velocity Law for

Cylinder, Cones and Composite Shapes

**Project No.: NPG-Re3d-442-1-52
Copy No.: 11
No. of Pages: 8**

Date: JAN 21 1952

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NFO-44708

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11 May 1951
Major components of warhead, including steel outer cylinder, aluminum inner cylinder, spacer disc, gasket, and spacer studs.

APPENDIX A
Figure 1



Figure 1

NPP9-44709

11 May 1951
Assembled warhead; showing inner cylinder held in position by spacer studs at top,
and spacer disc at bottom.

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APPENDIX A

Figure 2

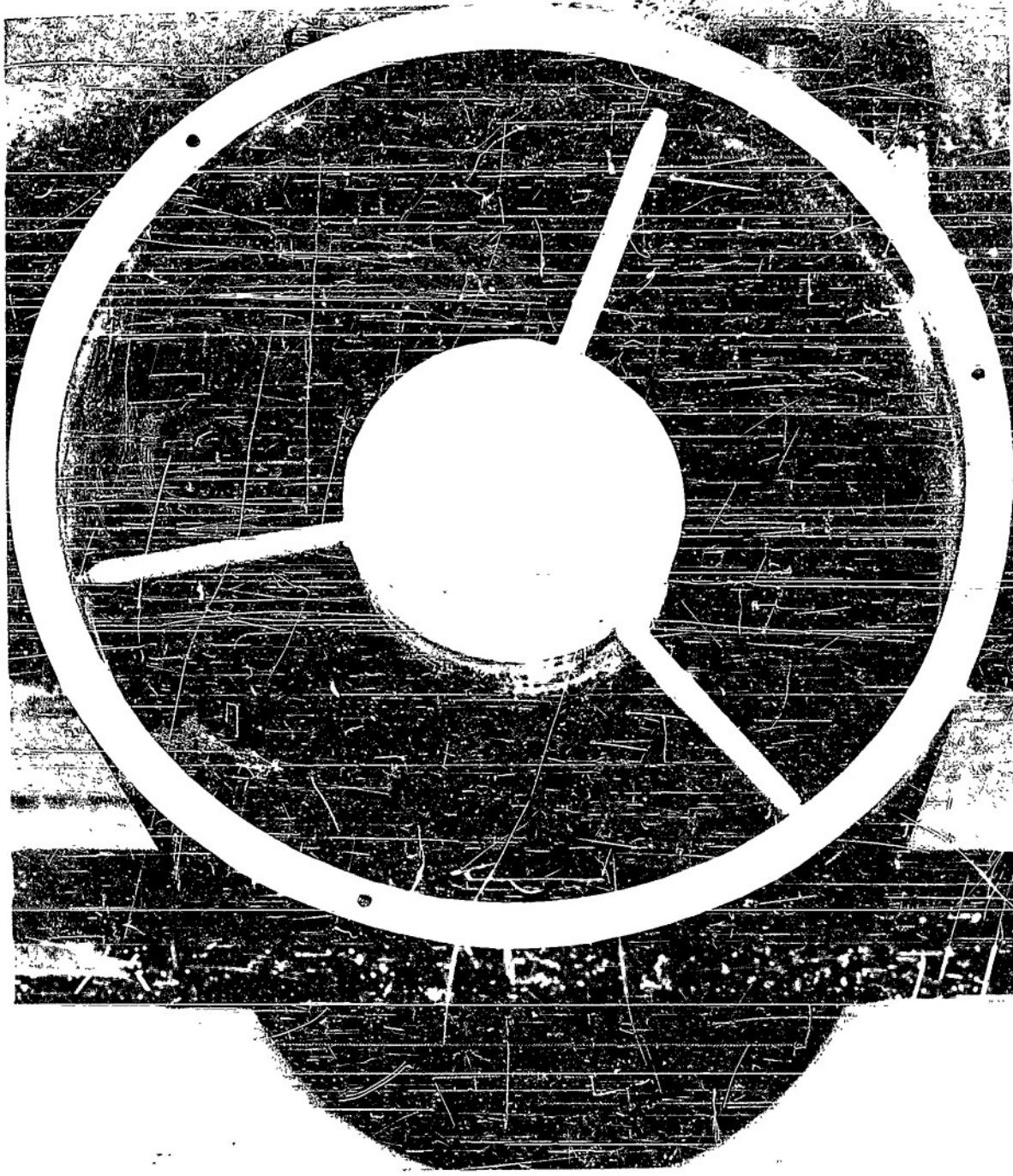
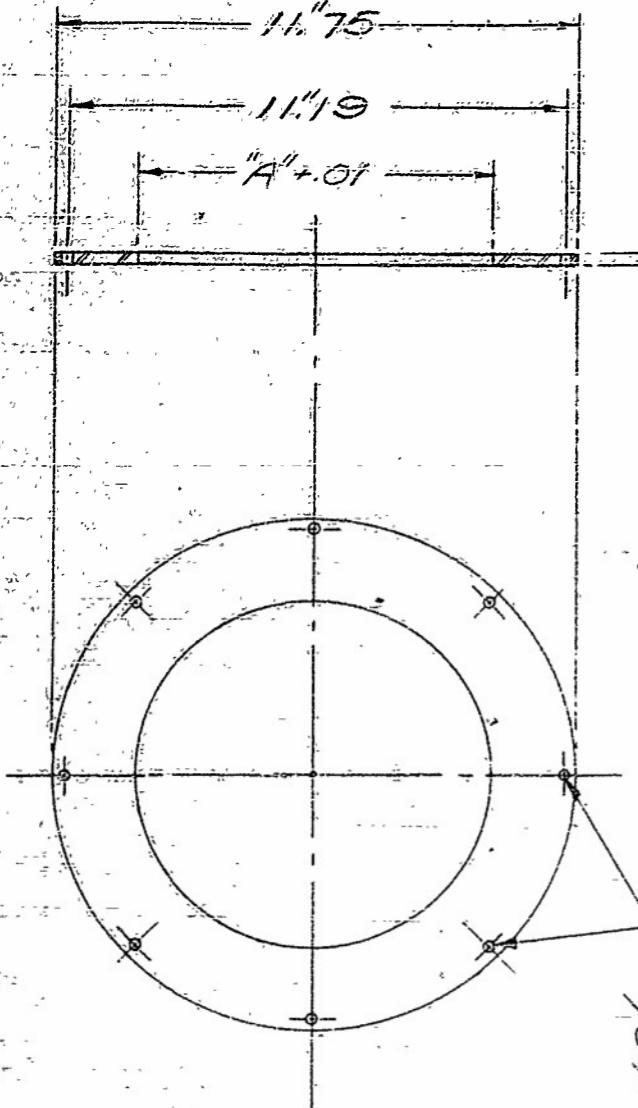


Figure 2

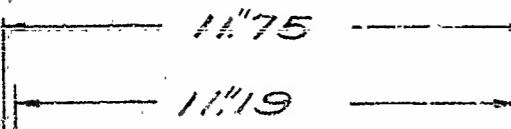
② EASE REVERSE

2
205
0.25
0.05

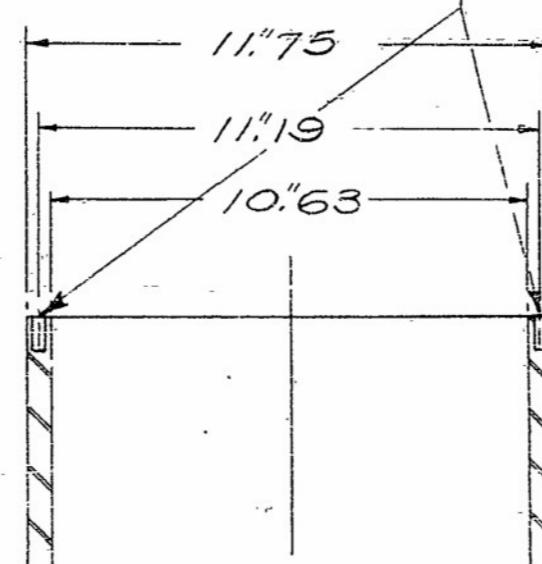


7/16" DIA. HOLES

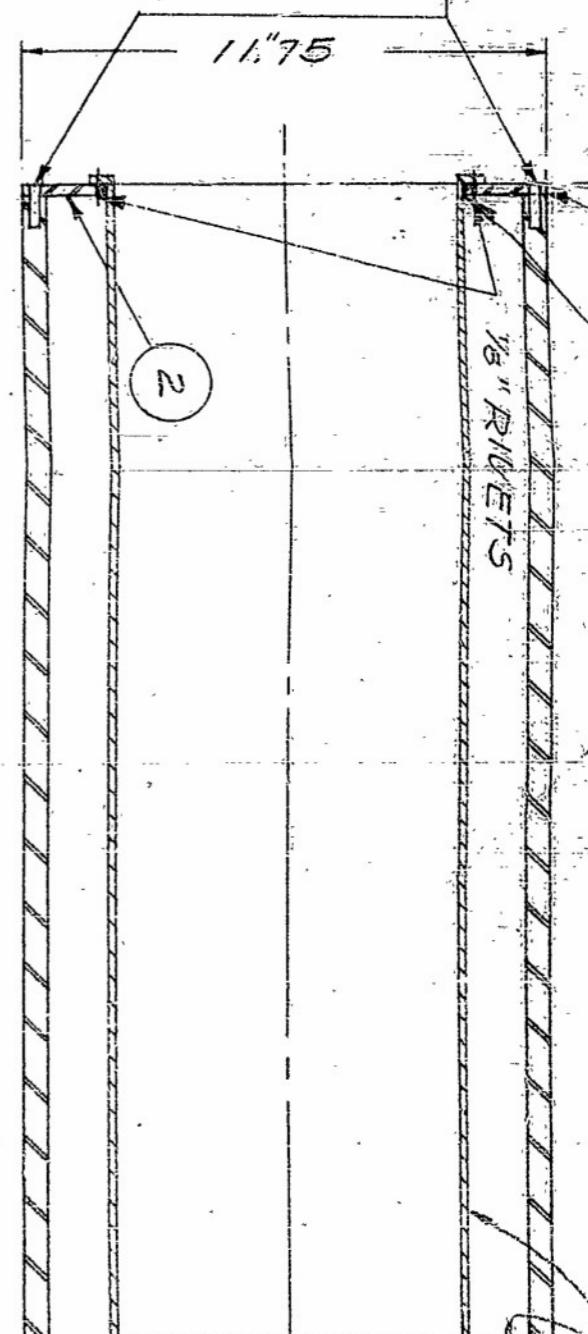
41 BODY



DRILL AND TAP
FOR 1/4" SCREWS



④ ASSEMBLY



152 (CIRSKOID)
104 PER SET.

CONTINUOUS SCREWS WITH SLOPING HEADS
BOLTED SCREWS WITH SLOPING HEADS
30.675

30.5" AND MAX (40)

3/8" LOCK STUD

1/4" CAP SCREWS

BREAK SHAPED EDGE - 3/8" STD. THD.

"B" - - - - - 1/2"

"A"	"B"
4"	3 1/2"
5"	2 1/2"
3"	1 1/2"

SPACE RETAINER

REF: APP-220
1/32" (GASKIN)
PAPER. SERL

30.5"

29.0"

30.5"

DRILL AND TAP FOR 3/8" STUD (3 HOLES)
FOR 1/4" SCREWS

BODY

1/25

7/64" DIA. HOLES

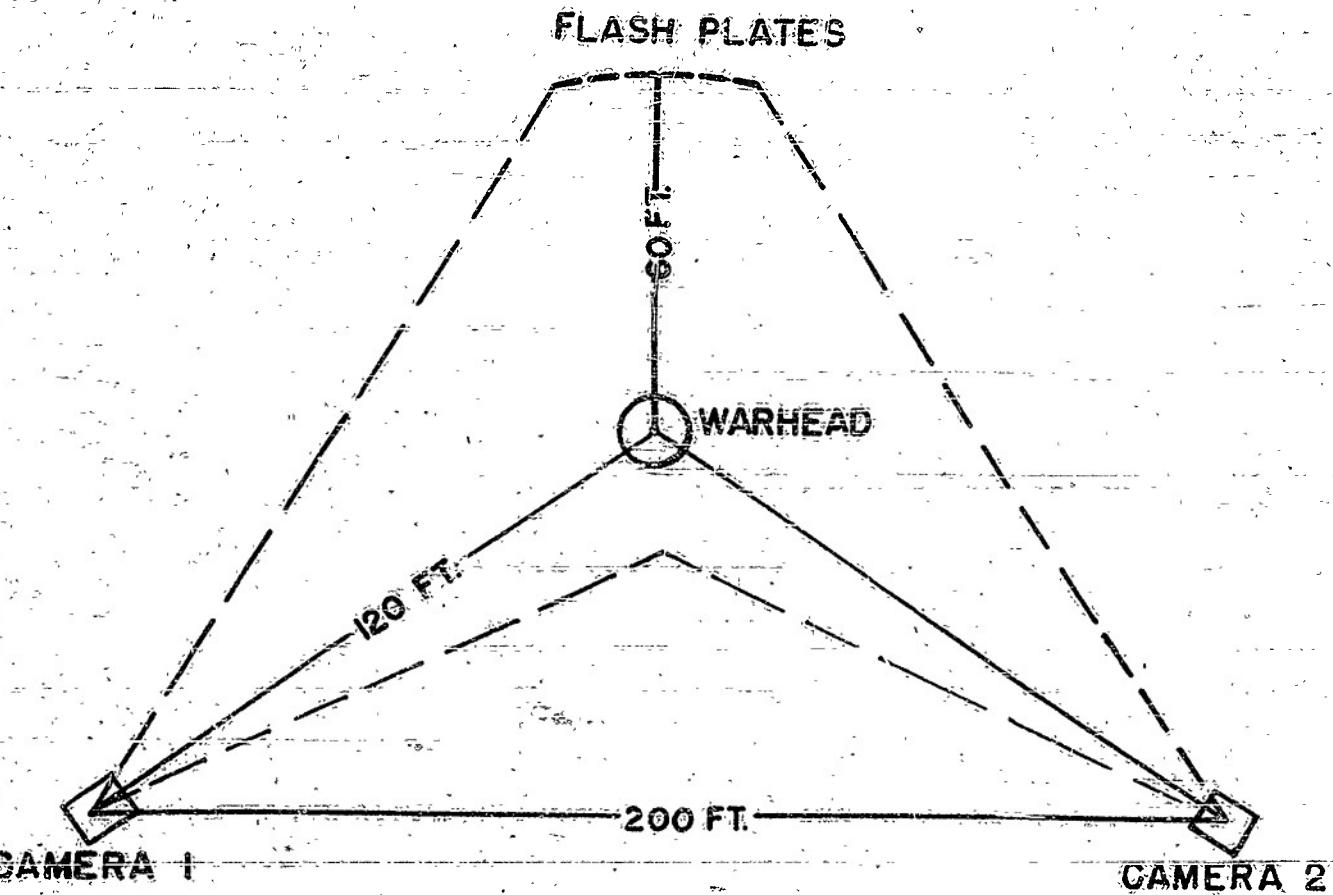
11.75

11.19

(3)

CONE PLATE

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60 FT. RADIUS FRAGMENTATION ARENA

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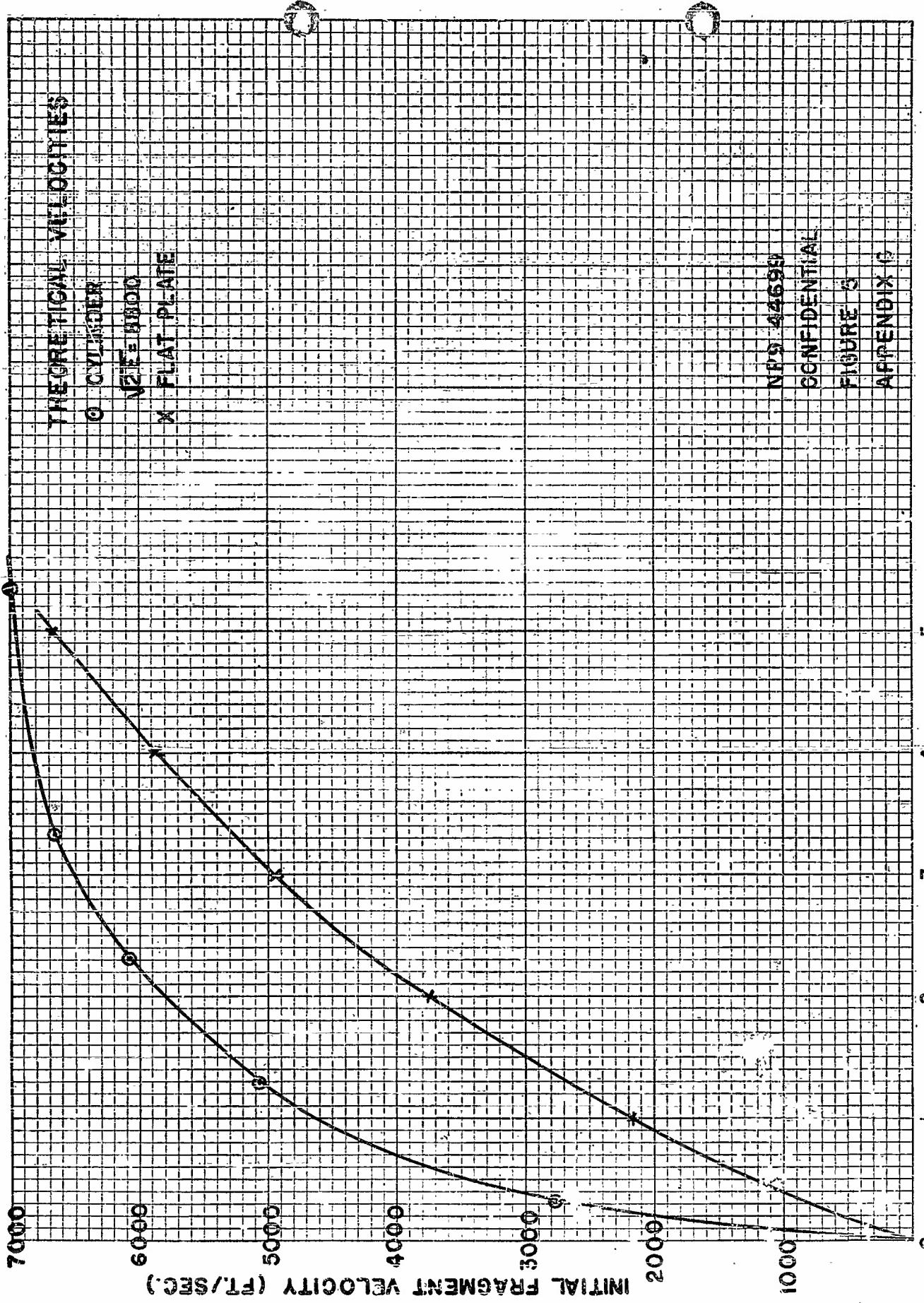
FIGURE 4

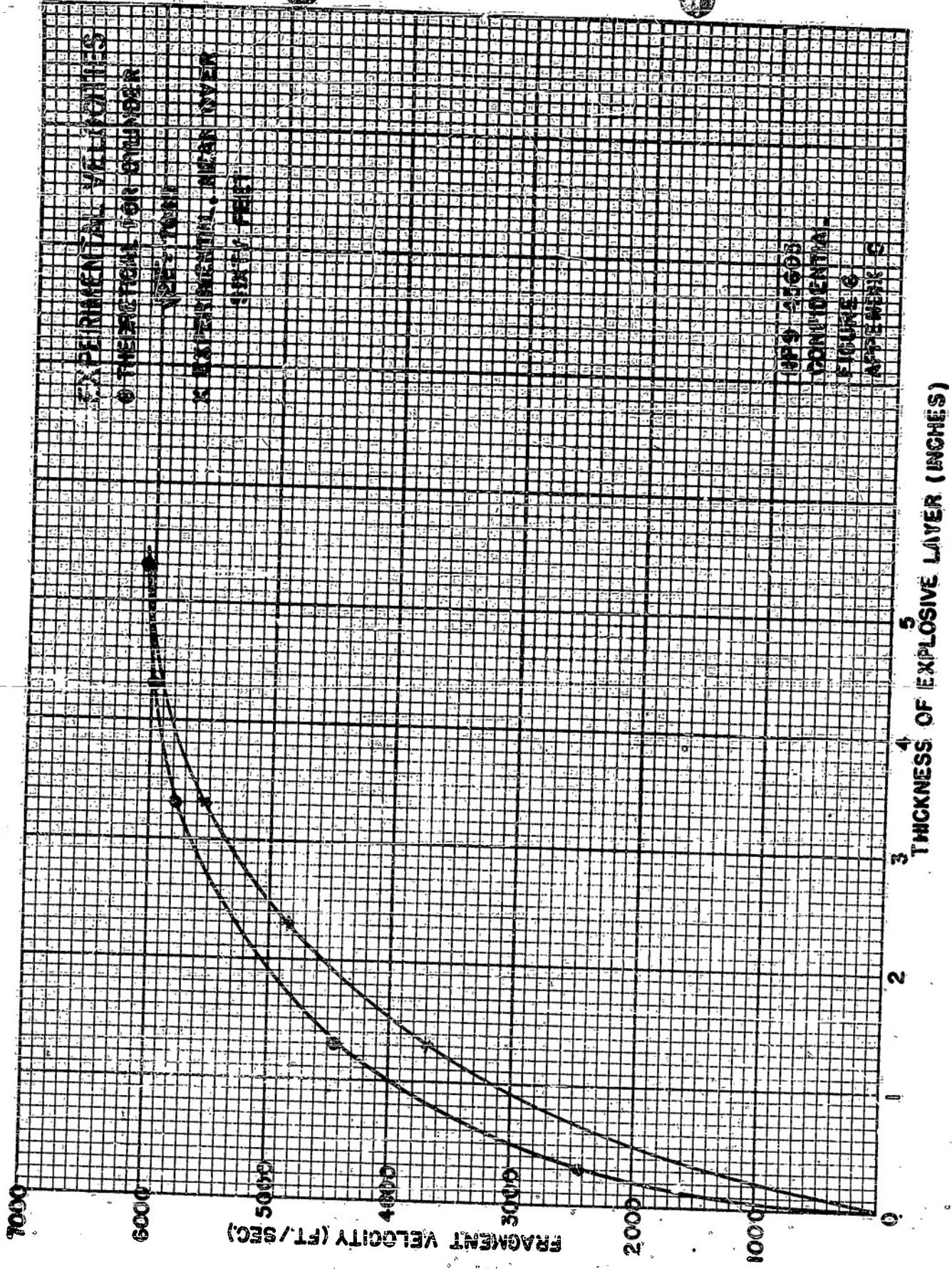
APPENDIX B

THICKNESS OF EXPLOSIVE LAYER (INCHES)

5
4
3
2
1
0

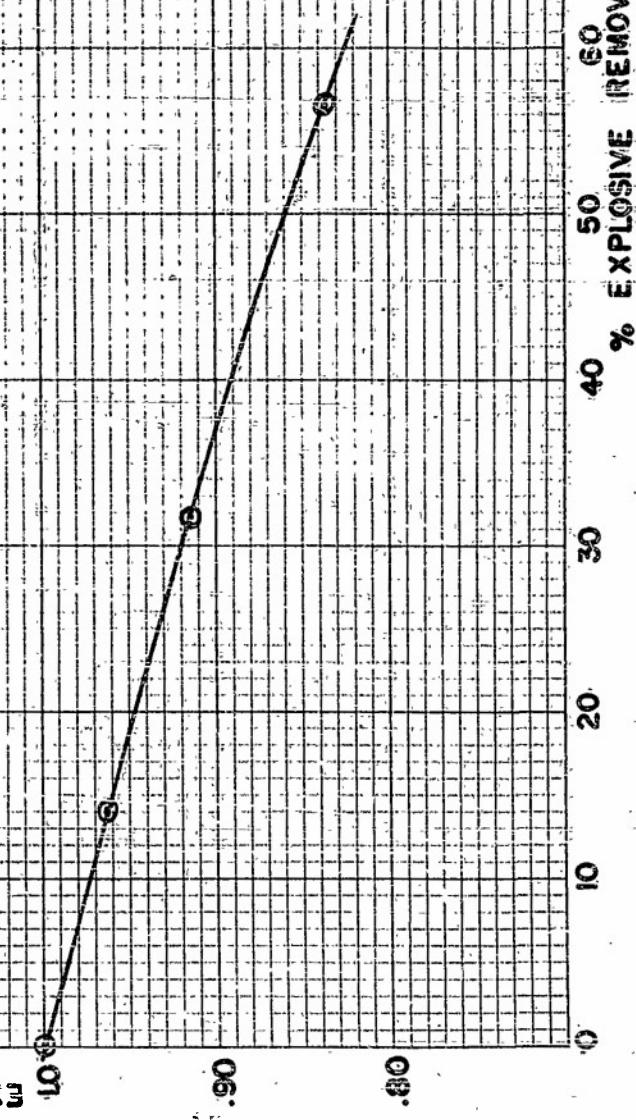
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FIGURE 3
REF ID: A69442690





REDUCTION OF FRAGMENT
VELOCITIES RESULTING FROM
AN AXIAL VOID

EXPERIMENTAL / GURNEY



MPS 4554
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FIGURE 7

APPENDIX C

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Fragment Velocity Law for
Cylinders, Cones and Composite Shapes

TABLE I

FRAGMENT VELOCITY DATA

35mm Fastax Camera

Ex. 14

Total weight 352.00 lbs.

Explosive Thickness 5/32", Full Lead Center Hit

3510 frames per sec.

Comp. C-3

Fillet Weight 154.00 lbs.

Frame in which Hit Occurred	No. Fragments	Velocity (ft./sec.)
32	3	6590
33	11	6380
34	12	6190
35	6	6020
36	1	5850
37	6	5690
38	1	5540
39	1	5400
41	2	5140
42	2	5010
43	1	4790
44	1	4790
45	1	4660
46	1	4580
Median		5950
Average		5930

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Eastax Camera 2

3390 frames per sec.

No. 1 a

Comp. C-3

Total Weight 32.00 lbs.

Filler Weight 154.00 lbs.

Explosive Thickness 5"315, full load Center 0"

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (ft./sec.)</u>
32	7	6360
33	15	6170
34	15	5980
35	3	5810
36	5	5650
37	7	5500
38	3	5350
39	1	5220
40	1	5090
45	1	4520
Median		5830
Average		5890

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NPG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 1

Rd. 18

Total weight 334.50 lbs.

Explosive thickness 5.315, full load

3540 frames per sec.

Comp. C-3

Filler weight 154.50 lbs.

Center 0"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

32 5 6640

33 18 6440

34 8 6250

35 11 6070

36 3 5900

37 3 5740

38 1 5590

39 1 5450

41 1 5180

Median

6190

Average

6220

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

3450 frames per sec.

Rd. 12

Comp. C-3

Total Weight 334.50 lbs.

Filler Weight 154.50 lbs.

Explosive Thickness 5 $\frac{1}{3}$ 15, full load

Center 0"

<u>Frame in Which Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (ft./sec.)</u>
31	9	6630
32	17	6470
33	9	6270
34	11	6090
35	6	5910
36	3	5760
37	2	5590
38	3	5450
39	1	5310
40	1	5180
41	1	5050
<u>Median</u>		6250
<u>Average</u>		6180

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 1

3480 frames per sec.

Rd. 1C

Comp. C-3

Total Weight 338.00 lbs.

Filler weight 154.00 lbs.

Explosive Thickness 5"315, full load Center 0"

**Frame in Which
Hit Occurred**

No. Fragments

Velocity (ft./sec.)

32

1

6530

33

13

6330

34

21

6140

35

11

5970

36

6

5800

37

4

5640

38

1

5490

41

1

5090

Median

6020

Average

6060

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

3390 frames per sec.

Rd. 1C

Comp. C-3

Total Weight 338.00 lbs.

Filler weight 154.00 lbs.

Explosive Thickness 5.315, full lead

Center 0"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

31

1

6560

32

16

6360

33

19

6160

34

7

5980

35

5

5810

36

1

5650

37

3

5500

40

1

5090

41

1

4960

42

1

4840

Median

6030

Average

6060

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APPENDIX C

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NPG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera I

3240 frames per sec.

Rd. 24

Comp. C-3

Total Weight 318.00 lbs.

Filler Weight 134.00 lbs.

Explosive Thickness 3.315

Center 4"

Frame in which

Hit Occurred

No. Fragments

Velocity (ft./sec.)

35

7

5810

36

11

5650

37

14

5500

38

11

5350

39

5

5220

40

3

5080

41

3

4960

43

1

4730

44

1

4620

45

1

4520

46

1

4420

Median

5370

Average

5400

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

3240 frames per sec.

Rd. 2A

Comp. C-3

Total weight 318.00 lbs.

Filler weight 134.00 lbs.

Explosive thickness 3" 315

Center 4"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

34 6 5720

35 13 5550

36 13 5400

37 12 5250

38 2 5120

39 3 4980

40 1 4860

41 1 4740

42 2 4630

43 2 4520

45 1 4320

Median

5340

Average

5300

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Continued)

15mm Eastman Camera 1

3450 frames per sec.

Rd. 2 8

Comp. C-3

Total Weight 316.00 lbs.

Filler Weight 139.00 lbs.

Explosive Thickness 3.315

Center 4"

Frame in which

Hit Occurred

No. Fragments

Velocity (ft./sec.)

26	1	7960
32	1	6470
33	3	6270
34	11	6090
35	22	5910
36	13	5750
37	4	5590
38	4	5450
39	4	5310
40	3	5180
41	3	5050
42	2	4930
43	1	4810
48	1	4310

Median

5730

Average

5750

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Fragment Velocity Law for
Cylinders, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

3360 frames per sec.

RQ. 20

Comp. C-3

Total Weight 316.00 lbs.

Filles weight 139.00 lbs.

Explosive Thickness 3.315

Center 40°

Frame in which

<u>Hit Occurred</u>	<u>No. Fragments</u>	<u>Velocity (ft./sec.)</u>
32	3	6300
33	14	6110
34	12	5930
35	8	5760
36	2	5600
37	5	5450
38	2	5310
39	3	5170
40	1	5040
41	1	4920
42	1	4800
Median		5800
Average		5800

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Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd.)

35mm Fastax Camera 1

3540 frames per sec.

Rd. 2 C.

Comp. C-3

Total Weight 312.00 lbs.

Filler weight 134.50 lbs.

Explosive Thickness 3.315

Center 4"

Frame in which
hit occurred

No. FragmentsVelocity (ft./sec.)

34	1	6250
36	4	5900
37	14	5740
38	22	5590
39	5	5450
40	4	5310
41	3	5180
42	3	5060
44	2	4830
45	2	4720
46	1	4620
Median		5490
Average		5510

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APG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Eastax Camera 2

3540 frames per sec.

Rd. 2 C

Comp. C-3

Total Weight 312.00 lbs.

Fillet Weight 134.50 lbs.

Explosive Thickness 3" 312

Center 4"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

35 3 6670

36 14 5900

37 16 5740

38 17 5590

39 8 5450

40 3 5310

41 3 5180

43 2 4940

44 1 4830

45 1 4720

Median

5630

Average

5620

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SECURE INFORMATION

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APPENDIX C

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 1

Re. 34

Total Weight 291.45 lbs.

Explosive Thickness 2.315

89 Frames per sec.

Comp. C-4

Filler Weight 105.25 lbs.

Center 6"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

32	10	5010
33	11	4850
34	1	4710
35	1	4580
36	1	4450
37	2	4330
40	1	4000
41	1	3910
Median		4750
Average		4780

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NPG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

2610 frames per sec.

Rd. 3 "

Comp. C-3

Total Weight 291.25 lbs.

Filler Weight 105.25 lbs.

Explosive Thickness 2.315

Center 6"

Frame in Which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

29

6

5400

30

13

5220

31

2

5050

33

2

4750

34

1

4610

35

2

4470

36

1

4350

37

1

4230

38

1

4120

40

1

3920

Median

4970

Average

5000

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SECURITY INFORMATION

**Fragment Velocity Law for
Cylinder, Cones and Composite Shapes**

TABLE I (Cont'd)

35mm Fastax Camera 1

3390 frames per sec.

Ref. 38

Comp. C-3

Total Weight 291.25 lbs.

Filler Weight 109.75 lbs.

Explosive Thickness 2¹/₂15

Center 6"

**Frame In Which
Hit Occurred**

No. /Fragments

Velocity (ft./sec.)

40

3

5090

41

7

4960

42

18

4840

43

11

4730

44

8

4620

45

5

4520

46

2

4420

47

1

4330

48

1

4240

49

1

4150

50

2

4070

Median

4720

Average

4720

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd.)

35mm Fastax Camera 2

Rd. 3 B

Total Weight 291.25 lbs.

Explosive Thickness 2.315

3540 frames per sec.

Comp. C-3

Filler Weight 109.75 lbs.

Center 6"

Frame in Which
Hit Occurred

No. FragmentsVelocity (ft./sec.)

42 3 5220

42 5 5100

43 15 4980

44 10 4870

45 3 4760

46 5 4660

48 2 4460

50 1 4280

51 1 4200

52 1 4120

54 1 3970

Median

4830

Average

4840

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera I

2460 frames per sec.

Rd. 40

Comp. G-3

Total Weight 252.25 lbs.

Filler weight 72.00 lbs.

Explosive Thickness 1.315

Center 8"

Frame in Which

Hit OccurredNo. FragmentsVelocity (ft./sec.)

36

3

4090

37

4

3980

38

3

3870

39

4

3770

40

5

3680

41

3

3590

42

2

3500

43

1

3420

44

2

3350

45

2

3270

Median

3750

Average

3710

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 2

2160 frames per sec.

No. 4 C

Comp. C

Total Weight 252.25 lbs.

Filler Weight 72.00 lbs.

Explosive Thickness 1¹/315

Center 8"

Frame in which
Hit Occurred

No. Fragments

Velocity (ft./sec.)

32	2	4050
----	---	------

33	3	3930
----	---	------

34	6	3810
----	---	------

35	5	3700
----	---	------

36	6	3600
----	---	------

37	3	3500
----	---	------

38	2	3410
----	---	------

39	3	3330
----	---	------

40	1	3240
----	---	------

Median

3680

Average

3660

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NPG REPORT NO. 904

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera I

2430 frames per sec.

Rd. 46

Comp. C-3

Total Weight 258.25 lbs.

Filler Weight 70.25 lbs.

Explosive Thickness 1"315"

Center 8"

Frame in which
Hjt occurred

No. Fragments

Velocity (ft./sec.)

33	1	4420
34	1	4290
35	2	4160
36	4	4050
37	4	3940
38	8	3830
39	2	3740
40	3	3640
41	3	3550
46	1	3170
50	1	2920
Median		3370
Average		3830

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SECURITY INFORMATION

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

AEROMARINE LABORATORY CAMERA 2

No. 4

Total Weight 258.25 lbs.

Explosive Thickness 19315

2130 frames per sec.

Comp. C-3

Filler Weight 70.25 lbs.

Center 8"

Frame in Which
HIT Occurred

No. FragmentsVelocity (ft./sec.)

30 1 4260

31 1 4120

32 4 5990

33 6 3870

34 10 3760

35 2 3650

36 5 3550

37 3 3450

39 1 3280

44 1 2900

46 1 2760

Median 3700

Average 3700

Fragment Velocity Law for
Cylinder, Cones and Composite Shapes

TABLE I (Cont'd)

35mm Fastax Camera 1

3360 frames per sec.

No. 4 C

Comp. C-3

Total Weight 255.00 lbs.

Filler weight 72.00 lbs.

Explosive Thickness 19.215

Center 8"

Frame in Which

Hit Occurred

No. Fragments

Velocity (ft./sec.)

47

2

4290

51

3

3960

52

4

3880

53

6

3800

54

6

3730

55

13

3670

56

7

3600

58

3

3480

59

4

3420

62

5

3250

63

1

3200

64

1

3150

65

1

3100

66

1

3050

67

2

3010

Median

3600

Average

3610

Fragment Velocity Law for
Cylinders, Cones and Composite Shapes

TABLE I (Cont'd.)

35mm Fastax Camera 2

3240 frames per sec.

Rd. 4 C

Comp. C-3

Total Weight 255.00 lbs.

Filler Weight 72.00 lbs.

Explosive Thickness 1.7315

Center 8"

Frame in Which
Hit Occurred

No. FragmentsVelocity (ft./sec.)

44	1	4420
45	1	4320
49	3	3970
50	5	3890
51	6	3810
52	10	3740
53	7	3670
54	2	3500
55	3	3530
56	4	3470
58	1	3350
59	2	3290
62	1	3140
63	1	3090
64	1	3040
<u>Median</u>		3730
<u>Average</u>		3690

**Fragment Velocity Law for
Cylinder, Cones and Composite Shapes**

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Fragment Velocity Law for
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